

Full Length Research Paper

Impact of fiber shape on mechanical behavior of steel fiber in fiber reinforced concrete FRC

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Fiber pull-out process is the main micro-mechanism that governs post-cracking behaviour of short steel fiber reinforced concrete structural beams. A detailed analysis of the fiber pull-out process provides understanding about the role of different micro-mechanisms involved in the pull-out process and leads to conclusions about the optimal fiber shape as well as the optimal properties of the matrix. Different steel fiber shapes involve different micro-mechanisms in the pull-out process. Initially fibers and the surrounding concrete matrix deform elastically. The linear elastic behaviour of the fiber-matrix system is interrupted by interface debonding which occurs due to overall weak bonding between the concrete matrix and the surface of the steel fiber. Shear crack propagates and the interface debonding continues until whole length of the fiber has parted from the surrounding concrete matrix. At that point the further applied pull-out load is resisted only by friction forces resulting from fiber sliding out of the concrete matrix. In some cases, if steel fibers have sophisticated form (e.g., end hooks or corrugated form), much of the pull-out resistance can be achieved from straightening of the fibers. Straightening of steel fibers can only be possible if the surrounding concrete matrix has sufficiently enough strength to resist stress concentration at fiber edges. If surrounding concrete matrix is weak, the stress concentration causes failure of the brittle matrix and no pull-out resistance is obtained. Concrete matrix failure (spalling) is more likely to happen for cases with larger fiber diameters. This paper introduces experimental study relevant to impact of fiber shape on mechanical behavior of steel fiber in fiber reinforced concrete FRC using three femouse steel fiber types and different cases of embedded length into concrete matrix.

Key words: Fiber reinforced concrete (FRC), steel fiber, friction forces, bonding forces, debonding forces, pull-out, embedded length.

INTRODUCTION

Different three types of steel fiber are used in fiber reinforced concrete: Straight steel fiber, Steel fiber with end hooks (this type is usually named as Dramix) and steel fiber in corrugated form (usually is named as Tabix) (Figures 1, 2 and 3).

Tensile strength of steel fibers is between 400 and 1500 MPa. Strength of highly carbonated steel fibers may reach

about 2000 MPa. Young modulus is about 200 GPa. Fibers are isotropic or may be slightly anisotropic. Steel fiber concrete is widely used in different civil engineering applications, variety of fibers is commercially available, and this is the reason why practical engineers are more familiar with such fibers applications [Krasnikovs et al., 2007].

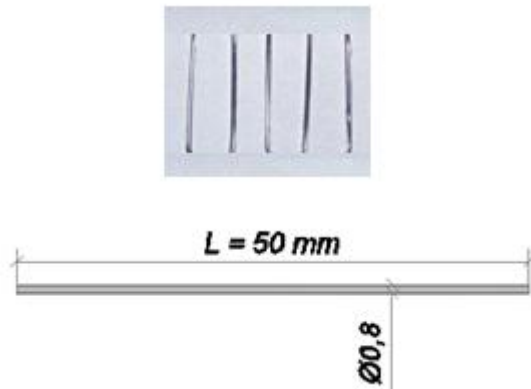


Figure 1. Straight steel fiber.

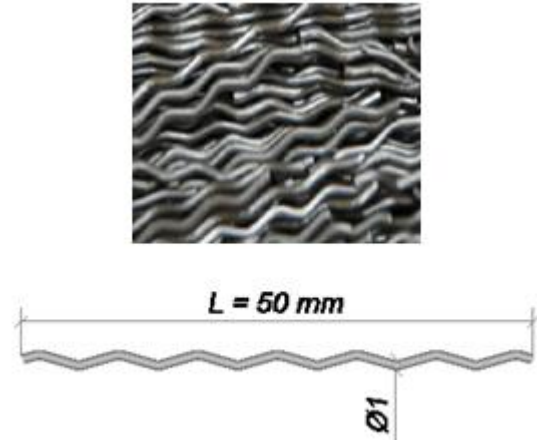


Figure 3. Steel fiber in corrugated form (Tabix).

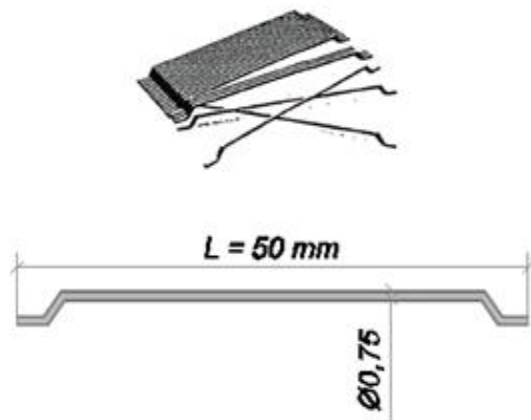


Figure 2. Steel fiber with end hooks (Dramix).



Figure 4. Steel mould used to prepare pull-out sample.

Laboratory experiments relevant to pull-out tests of these three different types of steel fiber are done using special steel moulds (Figure 4) and different values of steel fiber embedded length into concrete matrix, therefore four groups of samples have been prepared using various values of steel fiber embedded length equal to (0.1, 0.2, 0.3, 0.4 and 0.5 L).

The pull-out experiments lead us to draw conclusions regarding the influence of different fiber shapes and different embedded lengths. Straight fibers, Dramix fibers (with end hooks) and Tabix fibers (corrugated form) have been investigated and compared.

MATERIALS AND METHODS

Concrete mix design

Important factor is the ability to produce concrete mix with

desired properties. There are several technological aspects like workability, flowability of the concrete mix that very often limit theoretical possibilities of this material in practical applications. In order to avoid problems with workability and similar, special mix design programme has been developed for steel fiber reinforced concrete which allows high fractions of steel fibers to be mixed in the mix during preparation (Table 1).

Pull-out test samples

Experimental samples of steel fiber embedded into the concrete matrix are prepared in the lab and sorted in four groups according to the value of steel fiber embedded length (0.1, 0.2, 0.3, 0.4 and 0.5 L) where L is the total length of steel fiber and equal to 5 cm. Steel fiber in all samples is placed in right angle with the free edge of each part of the concrete, where plastic chair is used at the middle of the mould to divide the total volume of the

Table 1. Components of the concrete mix which is used in pull-out experiments.

Designation:	F50a	
	1 m ³	1 liter
Components		
CEM II 42.5 A-V	556	556.00
Sand 0.3/2.5 mm	863	863.00
Sand 0/0.5 mm	288	288.00
Filler (Dolomite powder)	150	150.00
Microsilica	81	81.00
Water	247.0	247.00
SIKA EVO 26	9.00	9.00
SIKA AER S (10%)	2.00	2.00
Total:	2196.00	2196.00

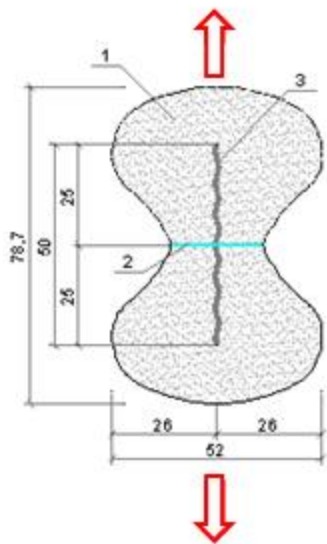


Figure 5. Schematic sample of steel fiber in the concrete: 1. Concrete matrix; 2. Plastic chair; 3. Steel fiber.

concrete into two separated parts and to keep the orientation of the fiber perpendicular with the surface of this plastic chair (Figure 5).

Observing of mechanical behaviour

Fiber pull-out experimental results are crucial for FRC mix design and preparation as by knowing the pull-out behaviour of each fiber we are able to obtain desired properties of the FRC beam. Therefore pull-out tests will be



Figure 6. Laboratory pull-out experiment.

done for all samples after 28 days from the preparation day of each sample. Lab equipment can be used to apply tension loads starting from zero and slowly speed to observe the mechanical behavior of steel fiber under pull-out test and to obtain the maximum tensile strength of each fiber in all samples (Figure 6).

RESULTS AND DISCUSSION

Straight fibers, Dramix fibers (with end hooks) and Tabix fibers (corrugated form) have been investigated and compared. Straight steel fibers showed the least resistance to the applied pull-out load as they counteract the applied load only by weak bonding forces and friction forces during fiber slide-out (Figure 7).

Dramix fibers showed more than 3 times higher maximal

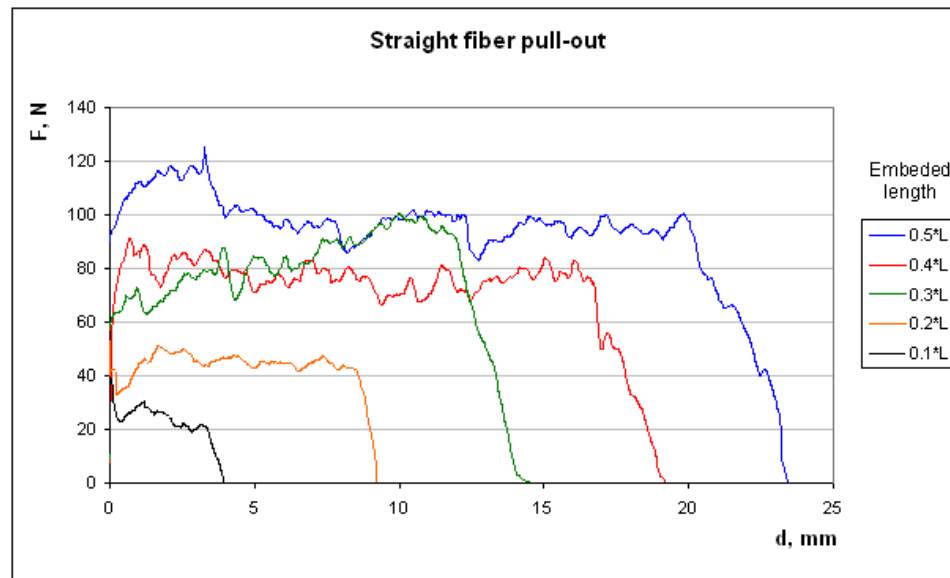


Figure 7. Straight fiber pull-out results.

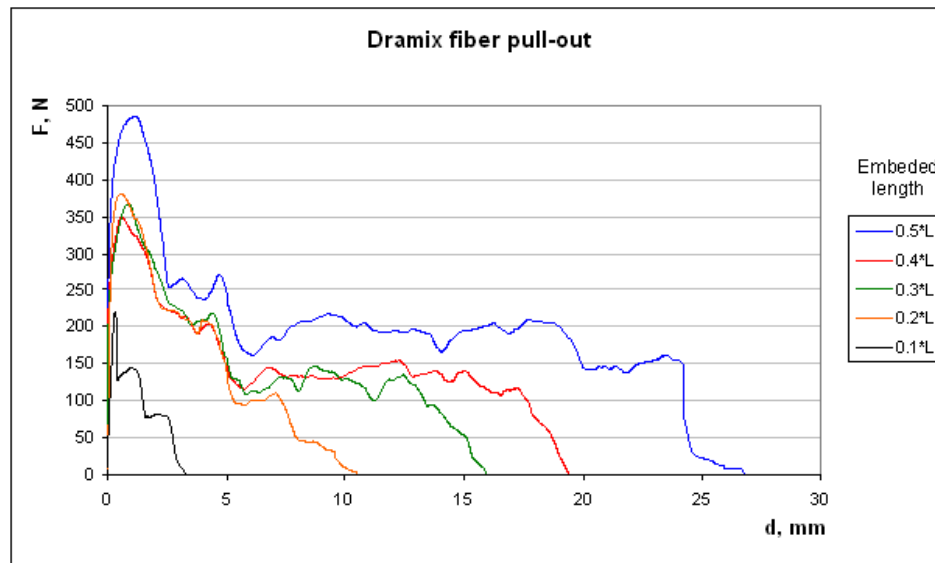


Figure 8. Dramix fiber pull-out results.

pull-out resistance load than straight fibers. The behaviour of a single Dramix fiber during pull-out loading is typical as shown on the graphs – maximal value at low pull-out displacement value with subsequent fall ahead. The pull-out curve for Dramix fiber is then typical to increase due to straightening of the end hook when sliding out of the debonded channel. After complete straightening of the initially hooked fiber end, the applied pull-out load is counteracted only by friction forces just like for straight

fibers (Figure 8).

Tabix fibers are of the most sophisticated form, therefore its pull-out behaviour should also be more complex comparing to previously observed straight and Dramix fibers (Figure 9).

In fact, as seen from the experimental pull-out results, the pull-out behaviour of corrugated Tabix fibers is very much similar to Dramix fibers with just one end hook. First the maximal pull-out load value is reached which is then

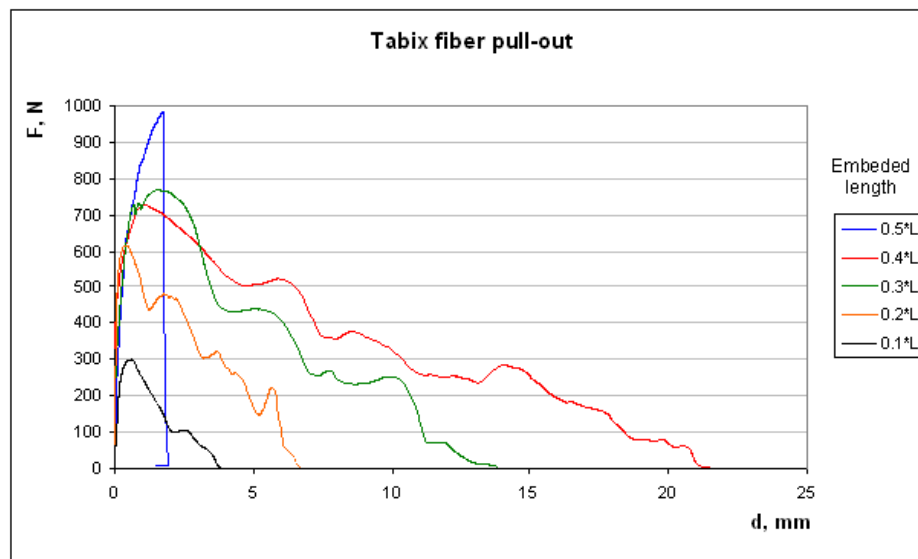


Figure 9. Tabix fiber pull-out results.

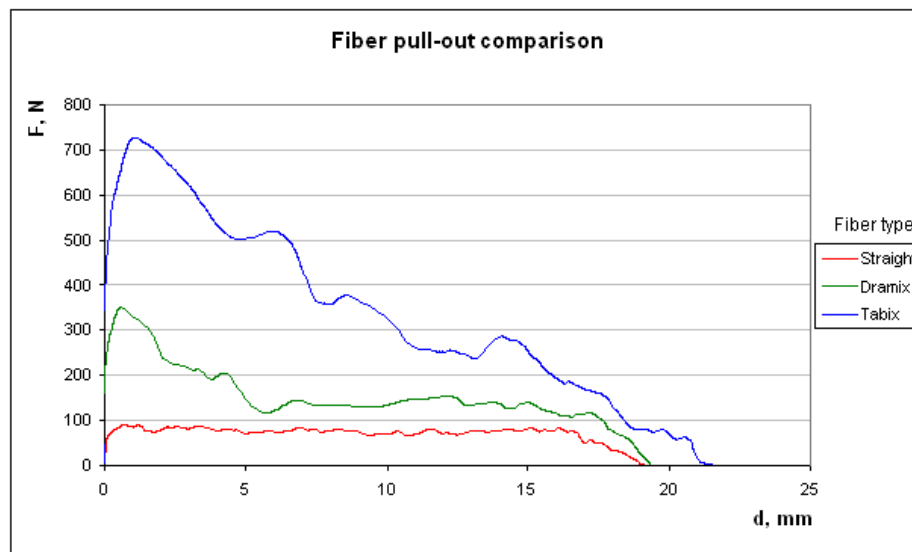


Figure 10. Straight, Dramix and Tabix fiber pull-out Comparison.

followed by fiber slide-out with straightening. The difference between Tabix and Dramix fibers is that Tabix fibers have more volume that undergoes straightening process and it is harder to distinguish the involvement of the friction forces as the straightening proceeds in steps. According to the experimental results, the maximal fiber pull-out load for Tabix fibers is more than 2 times higher than for Dramix fibers and more than 7 times higher than for straight fibers. These results show the significance and usefulness of the corrugated shape of steel fibers. In fact,

the experiment showed that with symmetrical embedded length (25 mm) the applied pull-out load causes Tabix fibers to break which leads to conclude that the strength of the reinforcement (fiber) is efficiently used.

For embedded lengths less than half of a fiber length ($L_b < 0,5 L$) no fiber breaking was encountered (with exceptions for some distinct samples) with the vast majority of tested fibers pulling out. Tabix fibers are rather sensitive to embedded length factor as the maximum pull-out load and the pull-out character itself changes with

the number of embedded waves of the corrugated fiber end. At extremely small embedded lengths the character of the pull-out curve changes completely as the pull-out occurs without fiber straightening because the concrete matrix fails due to overload from stress concentration. As it is seen in the graphs Dramix fibers can be divided in three groups depending on the embedded length. First one is the symmetrically embedded fiber which results in maximal pull-out load. The second group includes Dramix fibers with embedded lengths from $0,2 \cdot L$ to $0,4 \cdot L$ as they all correspond to approximately the same peak value (which is logical considering that there is only one fiber end hook that undergoes straightening) and very similar post-peak behaviour. The third and final group can be defined for extremely small embedded lengths ($L < 0,1 \cdot L$) as the pull-out behaviour is different due to matrix spalling (similar like for Tabix fibers). For straight fibers, the factor of embedded length is the most difficult to evaluate. The post-peak curve is very often highly non-linear due to many factors including initial misalignment of the fiber with the respect to loading direction and vice versa that leads to increased friction force. Therefore general conclusions regarding the embeded length factor can be drawn only for "shaped" steel fibers (Dramix and Tabix) (Figure 10).

Conclusions

- Straight steel fibers showed the least resistance to the applied pull-out load as they counteract the applied load only by weak bonding forces and friction forces during fiber slide-out.
- Dramix fibers showed more than 3 times higher maximal pull-out resistance load than straight fibers.
- Tabix fibers are of the most sophisticated form, therefore its pull-out behaviour should also be more complex comparing to previously observed straight and Dramix fibers.
- According to the experimental results, the maximal fiber pull-out load for Tabix fibers is more than 2 times higher than for Dramix fibers and more than 7 times higher than for straight fibers.
- For embedded lengths less than half of a fiber length ($L_b < 0,5 \cdot L$) no fiber breaking was encountered (with exceptions for some distinct samples) with the vast majority of tested fibers pulling out.
- Tabix fibers are rather sensitive to embedded length factor as the maximum pull-out load and the pull-out character itself changes with the number of embedded waves of the corrugated fiber end.

- At extremely small embedded lengths the character of the pull-out curve changes completely as the pull-out occurs without fiber straightening because the concrete matrix fails due to overload from stress concentration.
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